Environmental Impact of Forestry Transportation and Roading

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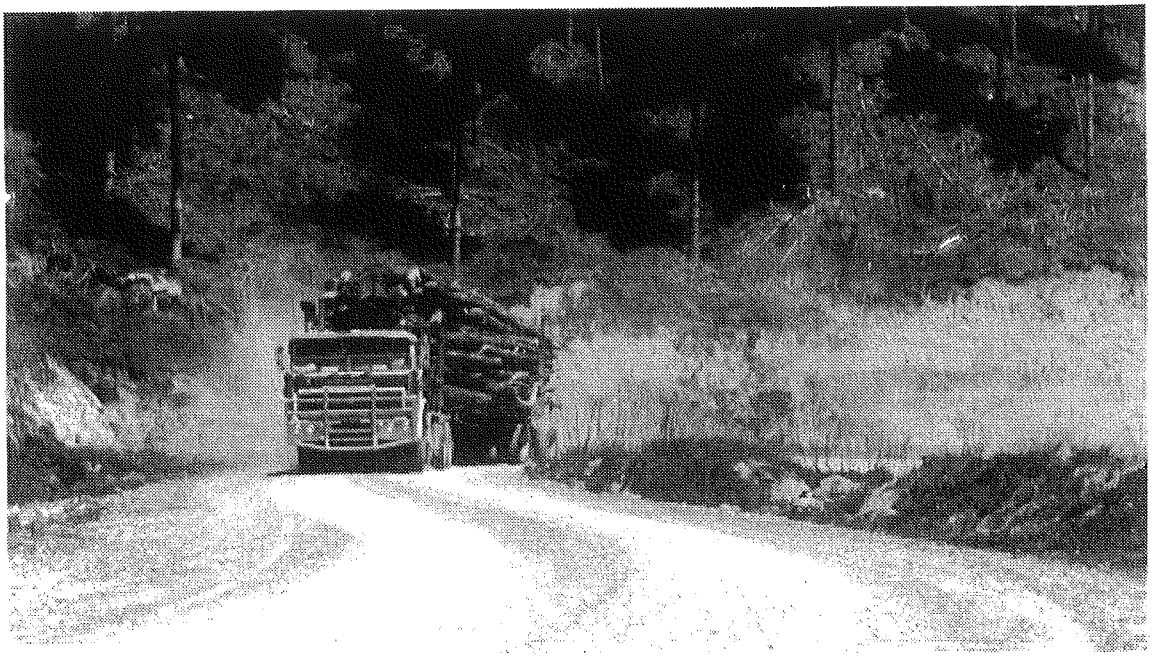

Figure 1 - Transportation and roading, important sectors of the growing forest industry

Abstract

As the transport and roading sector of the forest industry expands towards the year 2000, serious consideration must be given to addressing the environmental issues that confront it. Large areas of maturing forests, and a large number of maturing woodlots, will demand construction of new or greatly improved roads. Transportation of logs on public roads is expected to increase 43% in the decade to the year 2000.

Concerns about direct impacts of transportation and roading on the physical environment are added to by social and world-wide issues whose status are no less real in today's society. Higher environmental standards will continue to be expected from the physical aspects of roading and transportation. Additionally, new legislation such as the Resource Management Act, and to a lesser degree the Transit New Zealand Act, place greater emphasis on public participation in the decision making process. Upcoming regulations are therefore likely to reflect public perception, and it will be vital for the forest industry to maintain high standards in the eye of the public. This can be achieved by a combination of improved practices and public education.

Failure to resolve environmental concerns will see the roading and transportation sectors of the growing forest industry stifled by environmental regulation and social restraint.

Introduction

Forestry is gaining wider acceptance in many regions as a desirable land-use, and even as a "saviour" in badly eroded or nutrient depleted areas such as the east coast of the North Island or the sand dunes of the far north. Forestry expansion is providing many employment and development opportunities, and an increasing share of New Zealand's export earnings each year. Over 23 million cubic metres of timber will be harvested in the year 2005, a 62% increase from 1992 figures (MOF, 1993). However, aspects of the forest industry such as roading and transportation won't be exempt from the higher environmental performance standards being demanded by New Zealand public and law.

Increasing environmental concern by the public is bringing about a desire to balance economic gains with environmental protection, a concept encompassed by the term "sustainable development" (Bruntland Report, 1987). The meaning of "sustainable development" is defined as "development that meets the needs of the present generation without compromising the ability of future generations to meet their needs". Balancing development with impacts on the environment lends itself to value based decisions. New Zealand moved closer to this style of resource management with the introduction of the Resource Management Act (RMA).

While forestry transportation and roading are sectors directly reliant on each other, there is a contrast in the types of environmental issues facing them. Roading impacts are usually local and physical, while transportation impacts are more often linked to social and world-wide concerns. For this reason the two will be dealt with separately.

Transportation

Log transport in 1992 in New Zealand amounted to 858 million tonne kilometres, with 60% on state highways, 7% on local roads, and the remaining 33% on either private roads or railways (Olsen PF & Co., 1992). In addition to the expanding forestry resource, many business leaders speak of the need to generate value added products and aim to widely extend markets. These actions will result in more steps in transportation process. This increase in demand for transportation of forestry products must be considered alongside issues such as the government's commitment to maintaining net CO_2 emissions to 1990 levels, and public's desire to restrict increasing traffic density on our roads.

In October 1993 the New Zealand Road Transportation Association held its annual conference in Rotorua with the theme "Road Transport in the Environment". Speeches by key business and government officials indicated the range and diversity of these environmental transportation issues (Transport, 1993). The opening speech by the Transport Minister, Mr Rob Storey, stated that consideration of environmental issues will be increasingly important for the transport industry as a whole. There is the need to maintain New Zealand's "clean, green image" in order to successfully take advantage of an environmentally concerned world-wide market.

Ministry of Forestry chief executive, Dr. John Valentine, indicated forestry would grow 80% in the next 12 years, and that our existing transport system is not likely to be capable of absorbing this expansion within the existing structure. Log transport was expected to increase by 33% on public highways, and approximately 127% on local roads (MOF, 1993).

Regional Transportation Strategies

Each regional council in New Zealand is responsible for the management of transportation within their region. Environmental concerns regarding transportation at the regional level should be identified and reflected in their individual Regional Land Transport Strategy. The development and publication of these strategies is mandatory for each region under the Transit New Zealand Act.

At the global scale, the problem of achieving a sustainable transportation system is well encapsulated by three of Canterbury's long term concerns (Canterbury R.C., 1993);

1. The regions communities rely on transportation services without which they are unsustainable.

2. The transportation system is unsustainable because its energy sources are fossil fuels, a finite resource.

3. The adverse effects of using current transport fuels on the local environment and communities and on global ecosystems are unacceptable.

At this global level there is clearly some conflict. Our dependence on the existing transportation infrastructure and technology is not "sustainable" in the true sense of the term. New Zealand's laws, however, explicitly integrate social and economic well-being into the definition of sustainability. Transportation strategies that raise this global issue of long term sustainability do not provide solutions to this problem, and merely conclude with the need to continue investigating modal shifts or alternative fuels.

The Swedish Environmental Protection Agency recognises that nobody knows yet what an optimum, environmentally sound transport system will look like, but have commenced a 25 year project to develop one. The first step is to formulate goals with regard to problems we are already aware of or suspect could arise. The next step is to describe a system that fulfils these goals, and final step is to implement such a system through providing incentives to change in this desired direction.

While these global problems remain in the short term "unsolvable", a number of concerns identified at the regional scale in the transportation strategies have direct implications on the forestry transportation sector.

Air Pollution

The release of vehicle emissions through the burning of fossil fuel can seriously harm the overall environment when either concentrated, such as smog in any large city (i.e. Christchurch), or through slow accumulation (i.e. ozone depletion and greenhouse effect).

The burning of fossil fuels in air reduces complex carbon chains into carbon dioxide (CO_2), water (H_2O), and a number of other by-products. Each litre of petrol or diesel used generates just over 2 kg of CO_2, which is the predominant greenhouse gas of concern. Along with many other countries at the Rio "Earth Summit" Conference, New Zealand committed itself to limiting CO_2 emissions in the year 2000 to 1990 levels. Road transport itself produces about 7.4 million tonnes of CO_2, or about 26% of New Zealands total (MfE, 1993). Of that only 42% was used by goods and service vehicles.

New Zealand is relying heavily on its expanding forest industry to play a vital role in achieving its global commitments

to reducing greenhouse gases. While carbon levels are in balance in non-production forests, CO_2 absorbed by trees in a production forest will store the carbon unless the timber is used for fuel or allowed to decay. A typical New Zealand production forest will store 5 tonnes of carbon per hectare per year. In the long term however, maintaining CO_2 levels will require a significant reduction in our dependence on fossil fuels for energy.

There are a large number of by-products from burning fossil fuels, most of which have a far more localised and immediate impacts on the public's health. Table 1 shows the exhaust emission factors of some of these "other" gases released from vehicles while travelling at relatively low speeds through a town. This shows that diesel, relative to petrol, in addition to being considerably more efficient, produces less of these hazardous gases. Most forestry transport vehicles are powered by diesel fuel, and this is clearly advantageous.

Fuel	Petrol	Diesel	LPG
Carbon Monoxide (CO)	25	1.5	2.0
Hydro-carbon (HC)	3.7	0.9	1.5
Nitrogen Oxides (NO_X)	1.7	0.9	1.25
Sulphur Dioxide (SO_2)	0.042	0.7	

Table 1 - Exhaust Emission Factors for Cars (g/km)
(reproduced from Waikato Regional Council Environmental Study, 1993)

Hydro-carbon gas is another greenhouse gas, while carbon monoxide is a very poisonous gas when in high concentrations. Significant reduction in these gases can be achieved by proper engine tuning and aides such as catalytic converters and vehicle emission testing. Both nitrogen oxides and sulphur dioxide contribute to the production of acid rain, and are responsible for the acidification of lakes and soils in Europe (Juritsch and Wiener, 1992).

Other common vehicle emissions that can impact on the environment, particularly human health, includes lead and suspended particulate matter. Lead compounds are particularly hazardous to children's health. Reducing or omitting lead in our petrol will avoid this problem. Suspended particulate matter, most commonly from diesel engines, can cause respiratory problems. Improved engine design can minimise this problem.

To achieve fuel reductions in the short term the growth in the transport industry needs to be matched by improvement in efficiency. While data is sparse, Ellis (1994) suggests that a 30% efficiency in road freight has been achieved in the last two decades through greater allowable gross weights, lower body weights and improved diesel engines. Without changing gross weight allowances on the roads, Collins (1993) predicted that the following factors could contribute towards fuel reductions by the year 2000:

Fleet improvement, 3%;
Vehicle operation, 3%;
Alternative fuels, 1.5%;
Demand management, 1.5%; and
Petrol pricing, 5%.

This in realistic terms adds up to about a 10% reduction in fuel use.

Noise and vibration

Operating in the early and late hours of the day smooths operations and minimises traffic congestion on the roads. In urban areas the increase in forestry traffic can be absorbed into the "background" or ambient noise levels of the roadway system. In rural communities, however, these increased operating requirements

can create quite a significant change in the existing noise levels. High intensity, short duration noise levels such as that from the use of engine-brakes or by empty trailers can be most irritating.

Considerable research has been carried out in the United States to determine what noise level (in decibels) either "highly annoys" people, or causes them to awaken (Finegold et al, 1994). The report establishes an exponential relationship, and this should be useful for determining the impact on the public from increased traffic noise.

Vehicles travelling over uneven surfaces will cause vibration of the ground. The magnitude of this vibration is dependant on the size of the undulations on the road, the mass and speed of the vehicle, and the structural strength of the road (Environment Waikato, 1993). Vibration can disturb sleep, and can result in damage to buildings. Rural roads are often built to lower design specifications and, as a consequence, vibration can result with the passage of heavy vehicles. This can be particularly a problem near schools during school hours, or in residential areas during the quite night hours.

Central tyre inflation is a proven method of reducing both the noise (especially the rattle of unladen trucks) and the vibration of vehicles travelling over uneven road surfaces (USDA, 1987).

Alternative modes of transport

In regions such as the Waikato and Bay of Plenty where forestry is prominent and a rail system is available, regional transport strategies discuss the issue of encouraging alternatives to road transport. Rail is reported to be about four times more economical in energy requirements (J/tonnes.kilometers) than road transport (Ellis, 1994; King, 1984). There are, however, high initial capital costs in extending railway lines to the resource, and the product still needs to be transported by road to reach the terminal, resulting in considerable double handling cost. Rail may also result in extended distances between source and destination.

In regions with forests close to the coastline such as in Marlborough and Gisborne, barging may be a preferable alternative to constructing roads and transporting products on steep and unstable soils (McConchie, 1992). In very sensitive or remote areas, the use of helicopters to extract timber may be appropriate (Kirk & Smith, 1992).

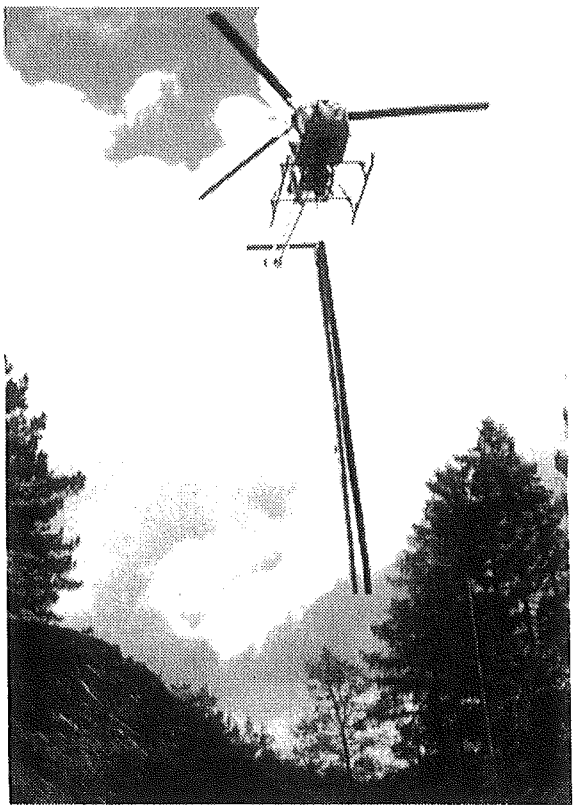

Figure 2 - Helicopter logging to reduce impacts in sensitive areas.

When planning a transportation network to service a forest for the future, simple cost-benefit analyses will need to be integrated with environmental and social considerations (sometimes termed "green

economics") to ensure appropriate long term solutions are developed. Possible new restrictions brought about by increased environmental standards or changes to the current tax regime (i.e. introduction of carbon taxes) will affect the viability of any proposed transportation system.

Public perception

At the RTA conference Bruce McIver, from the Road Transport Forum in Australia, pointed out that "Trucks scare people" and perceive them as a "threat" (Transport, 1993). This is because the industry is seen as being faceless, and having no control over itself. In his country where 77% of the total freight is moved by road, and 400,000 people directly rely on trucking for their employment, Bruce felt a poor job had been done to educate the public on the importance of the transport industry and what it did for them.

A recent Canadian survey on "perception of large trucks by Canadian drivers" yielded the following results (Prentice *et al*, 1989). Of those who responded, 41% said large trucks concern them on open roads, with female drivers being more concerned. The level of concern also increased with age. The three main concerns were that, trucks drive too fast, you can't see around them, and trucks carrying uncovered or unsecured loads. The top three safety concerns regarding the drivers were they drive too fast, follow too close and fall asleep at the wheel. Three quarters of respondents were concerned about passing a truck with a trailer, and 55% of drivers would support restrictions on truck use during peak driving times. Figure 3 shows the greatest concerns identified in the Canadian survey.

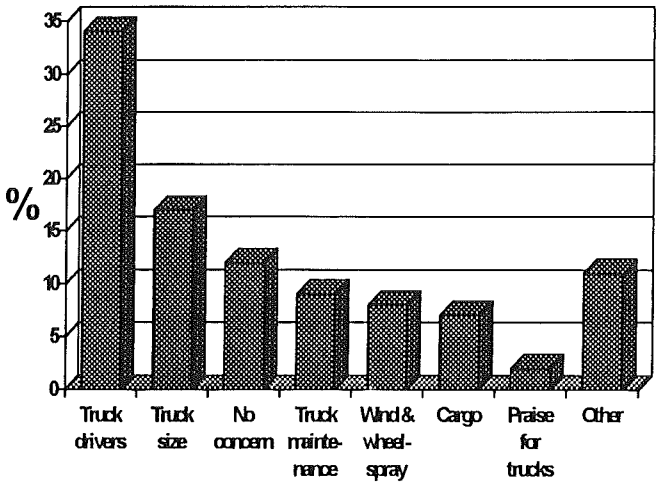

Figure 3 - Greatest concern about heavy traffic in Canada
(Reproduced from Prentice et al, 1989)

Only 12% of those questioned had no concern with regard to trucks operating on roads, while two percent actually gave an inverse response to the question praised the trucks.

Public perception of forestry transportation becomes increasingly more important in New Zealand. Laws such as the RMA and the Transit New Zealand Act give greater participatory powers to the public, and therefore regulations by the year 2000 are more likely to reflect public opinion. Raising overall driver standards, and educating the public on the necessity for an efficient transportation system and the benefits of forestry, will improve public perception and may in the long term reduce the need for transport regulations.

Spillages and Dust

Most regional transport strategies make specific reference to debris and spillages, mainly focussing on the impact of effluent discharge from stock trucks. In regions where forestry is prominent they also refer specifically to bark and soil coming off logging trucks. Forestry debris on public roads is not just an aesthetic issue, but also a concern for the safety of other

road users as previously identified in Figure 3.

Dust from the passage of heavy forestry traffic on unsealed and dry roads is not considered a health hazard but may have an undesirable nuisance effect for surrounding land owners, particularly horticulturalists. The most effective and long term solution is to seal the road, but costs may be prohibitive. Application of waste oil to reduce dust has recently been encouraged as cost effective and efficient by Transit New Zealand (1993); concerns associated with this practice are discussed in the roading section. Adverse impacts on water quality from surface run-off are mentioned in most strategies; this issue is also dealt with in the roading section.

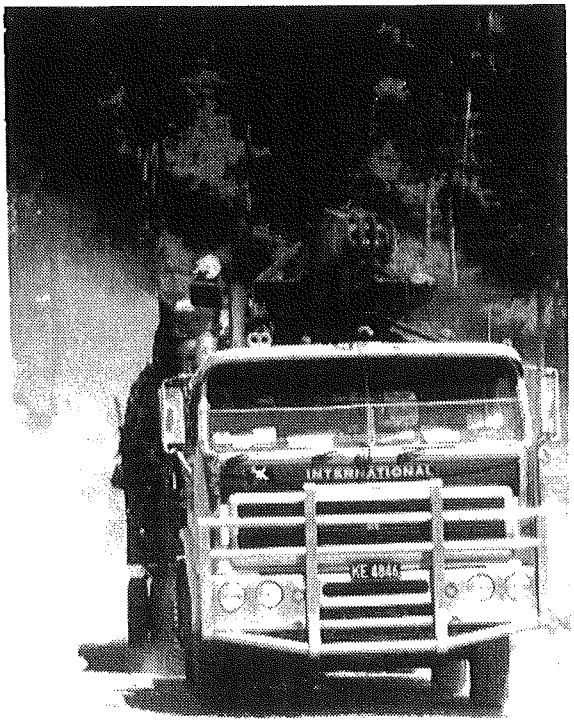

Figure 4 - Dust from heavy forestry vehicles on unsealed, dry roads.

Reducing future transportation impacts - a short discussion

Reducing general transport related environmental impacts such as air pollution, noise, vibration and spillages are likely to be required by increasing national and regional standards. Improved technologies and performance standards are likely to meet those challenges.

The greatest impacts on the industry are likely to emerge from increasing public participation in the decision making process. Already in one district guide-lines are in place for discouraging forestry trucks because of perceived social impacts and safety concerns. In direct response to public concern about heavy forestry vehicles, LIRO is developing a Drivers Code of Conduct. This document will not improve the overall image of the industry unless implemented by the trucking and forestry companies, and more importantly the truck drivers, to alleviate fear of heavy forestry vehicles.

Speaking at the RTA conference, deputy secretary for the Ministry for the Environment Lindsay Gowe, stressed efficiency. His talk focused not only on fuel and vehicle efficiency, but predicted that considerable savings can be made just by better management. This is supported by Ellis (1994) who indicates the greatest efficiency improvements are likely to come from improved load scheduling and co-operation between companies.

Roading

The roading network in a production forest is increasingly being recognised as a major asset of any company. Consequently greater effort is being made in planning, construction and maintenance of roads in the forests. Carefully designed and constructed roads add to our ability to provide for our social and economic well-being by providing access to our natural resources. There is also a greater understanding and awareness of the environmental impact of roading activities. Accelerated erosion of the

land, the impact of the sediment on water quality, the constriction of natural waterways and the disturbance of particularly sensitive areas are examples of direct environmental impacts. These types of impacts have raised public concern and have increased environmental performance standards for road construction and maintenance in many regions.

Regional Policy Statements

Roading, or any significant earthmoving activity, features in nearly all regional policy statements and land management plans. Like the transportation strategies, each regional council must have a policy statement in which they identify issues of concern to the region. Land management plans identify operations requiring resource consents. The public are expected to have considerable input into the development of these regional plans, and may formally object to any proposed activity that isn't in the permitted category in the policy statement or the land management plan.

The planning for the construction of new roads that require a resource consent will require an assessment of effects on the environment (AEE) as set out in Schedule Four of the RMA. These types of formalised environmental planning procedures are also known as environmental impact reports or assessments (EIR or EIA) and are becoming common. They are an effective method of ensuring due regard is given to the environmental impact of proposed operations (OECD, 1994).

Environmental impacts of roading can be broken down into two broad categories. The first are direct physical impacts of roading that should be considered when planning and constructing a new road. Secondary impacts from roading are on-going concerns that need to be addressed in the longer term.

Direct Impacts of Roading can include:

1 Redistribution of Large Amounts of both Top-Soil and Base Material

Top soil (also known as the "A" horizon) is typically the most nutrient rich and fertile upper layer of the soil, that can take centuries to develop. Its removal, particularly if subsequently eroded, significantly impacts the overall site capability of producing and sustaining crops. The importance of conserving this soil layer has been identified in nearly all regional policy statements. Impacts can be minimised by careful road design, and utilising or stabilising the removed top-soil.

2 Significant Changes to Natural Drainage Patterns

Roads are typically impermeable to water and therefore generate considerably more runoff than the surrounding land. Roads also intercept natural drainage patterns, re-diverting and channelling water. Significant diversions can impact the previous ecological make-up of the region.

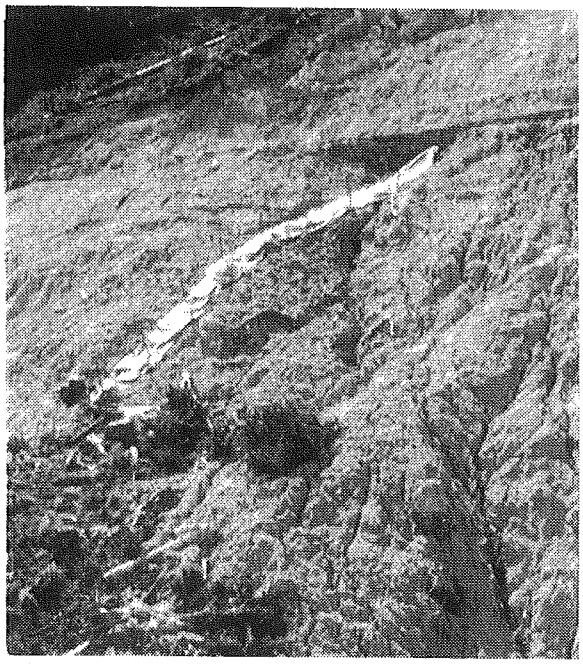

Figure 5 - Using a culvert "sock" to divert water past the fill slope.

Channelisation also gives the water additional velocity, greatly increasing its erosive powers. Impacts can be minimised or mitigated through carefully designed, constructed and maintained drainage control. This may include the use of sediment traps, culverts, fluming and culvert "socks" (Figure 5).

3 Constriction of Natural Waterways at Crossings

Permanent crossings of streams and rivers requires installation of culverts or bridges. Improper design can constrict the waterway and make them impassable to certain aquatic species. Additionally they be a major source and a direct pathway for sediment entering waterways. Impacts can be minimised by the use of guidelines to ensure appropriate crossing design (Mitchell, 1990: LIRO, 1993).

4 Significant Visual Changes to the Landscape

While the exposure of large areas of soil through the removal of vegetation clearly produces the greatest visual change, roading can also create significant adverse visual impact (Kilvert and Hartsough, 1993). The visual impact of roading is of particular concern if the roads are conspicuous, that is: if the roads are highly visible; if there is a large amount of contrast between the colour of the exposed soil (including cut and fill and side-cast); or if the layout of the road is visually striking.

The impact can be reduced by construction techniques such as end hauling as shown in Figure 6, and by rehabilitating the roadside. Careful design using aides such as guidelines will ensure impacts are minimised (USDA, 1977; LIRO, 1993). Oversowing and hydro-seeding can help stabilise fill slopes reduce the period of visual contrast (Smith and Fenton, 1993).

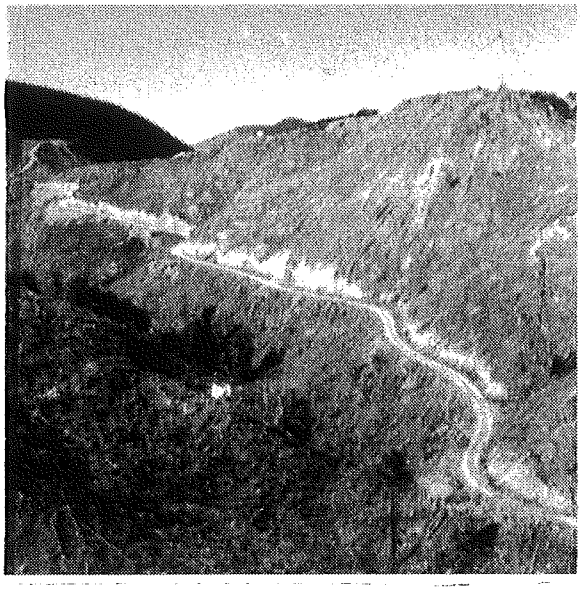

Figure 6 - End hauling to reduce visual impacts and excessive erosion.

5 Disturbance of Important Areas

In almost any district certain areas are of very high value or sensitivity and demand almost total protection. Examples of such areas are those with high ecological values (i.e. wetlands, endangered species habitat) and areas of cultural importance (i.e. Waahi Tapu sites). Impacting these areas can only be avoided by full consideration early on in the planning phase.

6 Excavation of Gravel Pits

The construction of new roads can require large amounts of fill for providing appropriate sub-base and base-course layers. This fill is often quarried, with the resulting quarry becoming a permanent feature on the landscape. Impacts can be mitigated by rehabilitating the site with previously removed and stored top-soil.

Secondary Impacts of Roading - can include erosion and concern about impacts on waterways and water quality which usually requires ongoing consideration :

- **Erosion**

The term erosion refers to the movement of soil (typically by water or wind processes), and the term sedimentation refers to these materials settling out. Erosion of roads is a concern because the material is likely to cause sedimentation of the waterways, unless intercepted downslope by vegetation or sediment traps. Within a production forest, roads, tracks and landings are the largest producer of sediment that ends up in waterways (Wallis and McMahon, 1994).

Excessive erosion from roads can often be attributed to inadequate drainage design, installation or maintenance. Typical signs of vehicular damage to unsealed forestry roads include:

a. Rutting (surface depression in the wheeled path). Usually caused by a considerable volume of heavy vehicles exceeding road strength.

b. Corrugations (closely spaced ridges and valleys (ripples) at regular intervals). Initially the road is deformed by heavy loads, and the corrugations are aggravated by bouncing of light trucks and trailers, and by acceleration and deceleration of vehicles.

c. Potholes (bowl shaped depressions in the road surface). Typically caused by excessive moisture getting in underneath the road seal. Other factors that can cause potholes are the width of road surface, the type of roading material, the conditions of the road shoulder and the volume of traffic.

d. Gravel loss - erosion of material due to weathering, traffic or blading.

Sediment pollutants are not limited to unsealed roads. A large United States study indicated that total solids and contaminants from sealed roads can also be significant (OECD, 1994).

Road wear, and vehicle wear, can be reduced by improved road construction, better vehicle suspension design, low tire inflation pressure, and vehicle slip reduction.

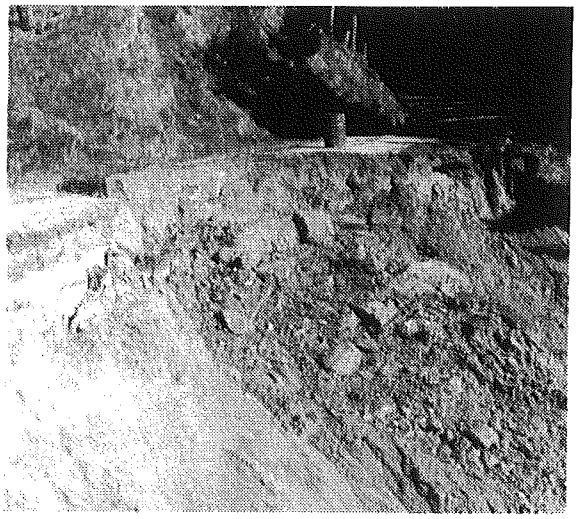

Figure 7 - Collapsed road from poor drainage control.

Guidelines for reducing erosion can be found in the Operations Database of the New Zealand Forest Code of Practice (LIRO, 1993). Additionally, some regional councils have earthmoving guidelines. Abiding by established best management practices avoids many of the problems that continue to occur to roads within our forests.

Application of waste oil on unsealed roads for dust control is a example of an issue currently under consideration by many regional councils. This method is still used extensively and promoted as being cost-effective by Transit New Zealand (Transit NZ News, 1993). Waste oil contains heavy metals from wear of engine components and some carcinogenic compounds (Works Environmental Mana-

gement, 1993), making it undesirable in significant concentrations in either our water or soils.

A recent study undertaken by Works Environmental Management (1993) for the Eastern Bay of Plenty District Council showed that approximately 30% of the waste oil applied by spraying had been lost from the road surface. The report concludes that such losses are not likely to be a direct hazard, but cannot quantify accumulated effects. Such results places the decision of such practices back into the hands of the council.

Waterways and Water Quality

Through increasing public awareness and the requirements of the RMA, the social, cultural and ecological importance of New Zealands waterways and water quality is being recognised. Water within our production forests is typically of relatively high quality (Mosely and Rowe, 1981; Dons, 1987; Cooper *et al*, 1987), and this is a very positive aspect of forestry as a land-use.

Careless roading and tracking can contribute significantly to sediment mobilisation (O'Loughlin, 1979; Vaughan, 1984). Mosely (1980) stated that approximately one-third of mobilised sediment entered the waterway. Sediment in waterways can detrimentally impact water quality, aquatic habitat and aquatic biota (Greynoth, 1979; Hickman, 1978; O'Loughlin, 1979).

In addition to roading being a primary sediment source, improperly designed crossings can severely impede fish passage and reduce the biodiversity within a waterway. Bridge and culvert capacity is typically designed to withstand a certain rainfall return period using a standard method. The movement of native fish populations is protected under the Freshwater Fisheries Regulations 1983 and Conservation Law Reform Act 1990 that states, "No person shall construct any culvert or ford any river, stream or water in such a way that the passage of fish may be impeded" (Mitchell, 1990).

Potential adverse impacts crossing waterways, and methods of reducing these impacts are summarised in the Forest Code of Practice. Proper design, compaction and stabilisation of fill and regular inspection and maintenance are all factors that help reduce the risk of bridge or culvert failure.

Reducing future roading impacts - a short discussion

Simple but effective technologies can greatly reduce likely environmental impacts, as well as reduce maintenance and optimise the availability of the road network asset. Simple products such as culvert socks or fluming should protect fill slopes and reduce the risk of road collapse. Improved construction techniques and proper drainage control will reduce on-going maintenance, and prolong the roads life.

Greater commitment to constructing roads with due regard for the environment will help improve forestry's public's image. Longer term thinking will justify these steps in economic terms.

Conclusion

Transportation requirements of the forest industry will increase to and beyond the year 2000. Through traditional methods such as lobbying and legislation, the public will have more power with regard to local and regional affairs. Forestry must respect this increased power of the people at a local level, and work with them to help minimise their concerns.

Many environmental issues relating to roading will be dealt with when forestry companies take a more careful and comprehensive approach to the planning and maintenance of roads. Considerable benefit is to be had from leading the way, as opposed to dragging the chain.

References

Canterbury Regional Council, (1993). "Regional Land Transport Strategy". Canterbury Regional Council Report 93(28).

Cooper, A.B., Hewitt, J.E., Cooke, J.G. (1987). "Land Use Impacts on Streamwater Nitrogen and Phosphorus". New Zealand Journal of Forestry Science 17(2/3): 179 - 92.

Dons, A. (1987). "Hydrology and Sediment Regime of a Pasture, Native Forest, and Pine Forest Catchment in the Central North Island, New Zealand". New Zealand Journal of Forestry Science 17(2/3): 161 - 78.

Ellis, A.J. (1994). "Changing Efficiency in the use of Petroleum Energy". Transport News, May edition Vol. 60 No. 5.

Environment Bay of Plenty, (1993). "Regional Land Transport Strategy". Resource Planning Publication, 93/1.

Environment Waikato, (1993). "Regional Land Transport Strategy". Environment Waikato Publication.

Environment Waikato (1993). "Environmental Transport Study: Resource Document 2". Environment Waikato Technical Publication No. 1993/5.

Finegold, L.S., Harris, C.S. and von Gierke, H.E. (1994). "Community Annoyance and Sleep Disturbance: Updated Criteria for Assessing the Impacts of General Transportation Noise on People". Noise Control Eng. J. 42 (1), Jan-Feb.

Greynoth, E. (1979). "Effects of Logging on Stream Environments and Faunas in Nelson". New Zealand Journal of Freshwater and Marine Research 13 (1), 79 - 109.

Hickman, R. (1978). "The Effect of Sedimentation on Shellfish and Fish". Ministry of Agriculture and Fisheries unpublished report.

Jones G. and Smith, M. (1993). "Central Tyre Inflation Truck Performance Testing in Kaingaroa Forest". Published by Logging Industry Research Organisation. Report Vol. 18 No. 18.

Juritsch, G. and Wiener, L. (1992). "Salzburger Bodenzustandsbericht". IOZ und Hausdruckerei, Alle 5010 Salzburg.

Kilvert, S. and Hartsough, B. (1993). "Visual Impacts of Forest Operations: Measuring Concern in New Zealand". Published by Logging Industry Research Organisation. Report Vol. 18 No. 9.

Kirk, P. & Smith, M. (1992). "Helicopter Logging: An Environmental Logging Case Study". Logging Industry Research Organisation. Report Vol. 17 No. 7.

Logging Industry Research Organisation (1993). "New Zealand Forest Code of Practice: Second Edition". (Editors L. Vaughan, R. Visser, and M. Smith).

Logging Industry Research Organisation, Rotorua.

McConchie, M. (1992). "Log Transportation by Barge: A Case Study in the Marlborough Sounds". Published by Logging Industry Research Organisation. Report Vol. 17 No. 18.

Ministry of Forestry (MOF), (1993). "Report from Forestry Road Funding Task Force".

Ministry for the Environment, (1993). "Climate Change Monitoring Network". June, 1993.

Mosley, M.P. (1980). "The Impact of Forest Road Erosion in the Dart Valley, Nelson". New Zealand Journal of Forestry 25 (2): 184 - 198.

Mosley, M.P. and Rowe L.K. (1981). "Low Flow Water Chemistry in Forested and Pasture Catchments, Mawheraiti River, Westland". New Zealand Journal of Marine and Freshwater Research Vol. 15: 307-320.

Organisation for Economic Co-operation and Development, (1994). "Environmental Impact Assessment of Roads". OECD Publication Service, 75775 Paris Cedex 16, France.

O'Loughlin, C.L. (1979). "Water Quality and Sediment Yield Consequences of Forest Practises in North Westland and Nelson". p 152 - 171. In: Seminar on Land Use in Relation to Water Quality and Quantity, Nelson, November 1979.

Olsen PF & Co. (1992). "Forestry Logging Traffic on New Zealand Roads".

Prentice, B.E., Oakley, W.A. and Hildebrand, M. (1989). "Perception of Large Truck by Canadian Drivers". Transport Institute, University of Manitoba.

Smith, M. and Fenton A. (1993). "Sediment Yields from Logging Tracks in Kaingaroa Forest". Published by Logging Industry Research Organisation. Report Vol. 18 No. 18.

Transport News (1993). November edition, Vol 59 No. 10.

USDA Forest Service, (1987). "National Central Tire Inflation Program - Boise National Forest Field Operational Tests". Project Report 8771 1201, Engineering Operations, San Dimas, CA.

USDA Forest Service, (1977). "National Forest Landscape Management". Government Printing Office Washington, D.C. 20402.

Vaughan, L. (1984). "Logging and the Environment; A Review of Research Findings and Management Practices". Logging Industry Research Association, Rotorua.

Wallis, G. and McMahon S. (1994) "The Impacts of Forest Management on Erosion and Sedimentation". Logging Industry Research Organisation, Rotorua. Report Vol. 19 No. 2.

Works Environmental Management (1993). "Monitoring of the Environmental Effects of Spraying Waste Oil on Roads". Report for Western Bay of Plenty District Council.

World Commission on Environment and Development (1987). "Our Common Future" (Bruntland Report). Oxford University Press.